

HEAT EXCHANGER FOR COOLING AIR

CROSS REFERENCE TO RELATED APPLICATION

This application is based on Japanese Patent Applications
5 No. 2002-204334 filed on July 12, 2002, No. 2002-204335 filed
on July 12, 2002, and No. 2003-82577 filed on March 25, 2003,
the disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

10 The present invention relates to a heat exchanger for
cooling air. More particularly, the present invention relates
to an evaporator for a refrigerator and a freezer.

BACKGROUND OF THE INVENTION

15 According to an evaporator for a refrigerator disclosed
in JP-A-2002-115934, tubes having substantially elliptic-
shaped cross-sections are arranged such that longitudinal axes
of the cross-sections are parallel to an air flow direction.
Outer fins are not provided between the tubes and the outer
20 surfaces of the tubes are generally exposed to the air. With
this configuration, frost is generated intensively at air
downstream portions of the tubes and the formation of frost
between tubes, which results in blocking of air passages, is
restricted. Accordingly, an air flow resistance reduces and
25 cooling capacity of the evaporator improves.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a heat exchanger for cooling air capable of improving efficiency of heat exchange.

5 It is another object of the present invention to provide a heat exchanger for cooling air capable of restricting the formation of frost thereon.

10 According to an aspect of the present invention, a heat exchanger for cooling air includes tubes through which fluid flows. The tubes are disposed such that outer surfaces are generally exposed to the air. The tubes have streamlined-shaped cross-sections so that air flows along the outer surfaces of the tubes.

15 Because air smoothly flows around the tubes without stagnating, it is less likely that moisture, which result in frost, will adhere on the outer surfaces of the tubes. Therefore, the adhesion of frost particles and the growth of frost on the tubes are restricted. Accordingly, an air flow resistance reduces and efficiency of heat exchange improves.

20 According to another aspect of the present invention, a heat exchanger includes a flat tube through which fluid flows. The flat tube is arranged such that a longitudinal centerline of its cross-section is parallel to an air flow direction and is corrugated in a direction perpendicular to the air flow
25 direction.

The heat exchanger is not provided with outer fins. Therefore, if moist air flows around the tube, moisture

condenses intensively at an air downstream position of the tube and grows into frost. Because the frost grows in a direction parallel to the air flow direction, the air flow is not obstructed. Accordingly, a resistance of air flow passing
5 around the tube reduces, so efficiency of heat exchange improves.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present
10 invention will become more apparent from the following detailed description made with reference to the accompanying drawings, in which like parts are designated by like reference numbers and in which:

Fig. 1 is a schematic perspective view of a refrigerated
15 vehicle according to the first embodiment of the present invention;

Fig. 2 is a schematic diagram of a vapor compression
refrigerant cycle system of the refrigerated vehicle according to the first embodiment of the present invention;

20 Fig. 3 is a perspective view of a rear end of the refrigerated vehicle according to the first embodiment of the present invention;

Fig. 4 is a perspective view of an evaporator of the
vapor compression refrigerant cycle system according to the
25 first embodiment of the present invention;

Fig. 5 is a partial perspective view of a core portion of the evaporator for explaining flows of air and refrigerant

according to the first embodiment of the present invention;

Fig. 6A is a cross-sectional view of a tube of the evaporator according to the first embodiment of the present invention;

5 Fig. 6B is an explanatory view of the tubes according to the first embodiment of the present invention;

Fig. 6C is a partial enlarged view of an air downstream portion of the tube shown in Fig. 6B for explaining an air stream around the air downstream portion of the tube according to the first embodiment of the present invention;

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Fig. 7 is a partial cross-sectional view of the evaporator for showing tube arrangement according to the first embodiment of the present invention;

Fig. 8 is a time chart for showing operation timings of an engine, doors and a defrosting valve according to the first embodiment of the present invention;

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Fig. 9A and 9B are cross-sectional views of tubes of the evaporator according to the second embodiment of the present invention;

20 Fig. 10 is a cross-sectional view of a tube of the evaporator according to the third embodiment of the present invention;

Fig. 11 is a cross-sectional view of a tube of the evaporator according to the fourth embodiment of the present invention;

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Fig. 12 is a psychrometric chart according to the fifth embodiment of the present invention;

Fig. 13 is a partial perspective view of a tube of the evaporator according to the sixth embodiment of the present invention;

Fig. 14 is a partial cross-sectional view of the tubes according to the sixth embodiment of the present invention;

Fig. 15A is a cross-sectional view of a tube of the evaporator according to the seventh embodiment of the present invention;

Fig. 15B is an explanatory view of the tube according to the seventh embodiment of the present invention; and

Fig. 15C is a partial enlarged view of an air downstream portion of the tube shown in Fig. 15B for explaining an air stream around the air downstream portion of the tube according to the seventh embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENT

Embodiments of the present invention will be described hereinafter with reference to drawings.

A heat exchanger for cooling air of the first embodiment is for example used for an evaporator 13 of a refrigerated vehicle 1, which transports goods or freights such as frozen food while maintaining them cold, as shown in Fig. 1.

The refrigerated vehicle 1 has a freezing container 2 for storing the freights. The freezing container 2 has an opening 18, and doors 3, 4 at its rear end. The freights are carried in and out through the opening 18.

A vapor compression refrigerant cycle system 5 for

cooling air in the freezing container 2 is mounted at the front of the refrigerated vehicle 1. As shown in Fig. 2, the system 5 includes a compressor 6, a condenser 9, an electric fan 10, a receiver 11, a pressure reducing device 12, and evaporator 13.

The compressor 6 is driven by an engine 8 through an electromagnetic clutch 7. The condenser 9 cools high-temperature, high-pressure refrigerant discharging from the compressor 6. The fan 10 blows cooling air to the condenser 9. The receiver 11 separates the refrigerant discharging from the condenser 9 into gas refrigerant and liquid refrigerant and discharges the liquid refrigerant to the pressure reducing device 12. The surplus refrigerant is stored in the receiver 11 as the liquid refrigerant.

The pressure reducing device 12 decompresses the liquid refrigerant. In the evaporator 13, the refrigerant from the pressure reducing device 12 evaporates by absorbing heat from air to be blown into the freezing container 2. The evaporator 13 will be described later in detail.

In addition, an accumulator 14 is provided between a refrigerant outlet of the evaporator 13 and a refrigerant inlet of the compressor 6. The accumulator 14 separates the refrigerant discharging from the evaporator 13 into gas refrigerant and liquid refrigerant. The gas refrigerant is sucked in the compressor 6 and the liquid refrigerant is stored in the accumulator 14.

A bypass 15 is disposed to introduce the high temperature

refrigerant (hot gas) from the compressor 6 to the evaporator 13 while bypassing the pressure reducing device 12. The bypass 15 is provided with a defrosting valve 16. The defrosting valve 16 is an electromagnetic valve. The defrosting valve 16 allows the hot gas to flow through the bypass 15.

A blower unit 19 is provided at the bottom of the opening 18 outside the freezing container 2. The blower 19 forms an air curtain for separating the inside of the freezing container 2 from the outside when the doors 3, 4 are open. The blower unit 19 includes cross flow fans 20, 21 each horizontally placed at the bottom of the opening 18. In the cross flow fans 20, 21, air flows within cross-sections that are perpendicular to axes of multi-blade cylindrical fans 20a, 21a (see JIS B0132 No. 1017).

Next, the evaporator 13 will be described in detail with reference to Figs. 4 to 6C. As shown in Fig. 4, the evaporator 13 includes a plurality of tubes 131 through which refrigerant flows and tanks 133 connected at longitudinal ends of the tubes 131 to communicate with the tubes 131. The tubes 131 constructs a core portion for exchanging heat between the refrigerant and air.

It is noted that outer fins, which are generally joined to outer surfaces of tubes, are not provided between tubes 131, so that outer surfaces of the tubes 131 are generally exposed to the air. As shown in Fig. 6A, the tubes 131 have streamlined-shaped cross-sections for restricting air streams around the tubes 131 from separating from the tubes 131 at

their air downstream portions (rear sides). (See, e.g. Fluids engineering, University of Tokyo Press). The streamlined shape is symmetric with respect to a longitudinal centerline CL of the cross-section. Air upstream portions (front sides) of the tubes 131 are gently curved. Hereinafter, the terms "downstream" and "upstream" are used with respect to a direction (A1) of air flowing through the evaporator 13.

In the embodiment, a teardrop shape (a wing shape) is employed as the streamlined shape. A dimension (thickness) of the tube 131 in a direction perpendicular to the centerline CL increases at a maximum value at a substantially middle position of the tube 131 with respect to the air flow direction A1 and reduces toward the air downstream position.

Each of the tubes 131 is formed with a plurality of refrigerant passages 132. The refrigerant passages 132 are parallel and in line from the upstream portions to the downstream position of the tube 131. In the embodiment, the tube 131 is formed by extrusion and drawing of aluminum, for example. Thus, the refrigerant passages 132 are formed at the same time as molding the tube 131.

As shown in Fig. 5, the tubes 131 are arranged in rows in directions perpendicular to the air flow direction A1. Further, as shown in Fig. 7, the tubes 131 are arranged in a staggered configuration. A first array pitch $Tp1$ of the tubes 131 of an upstream row is greater than a second array pitch $Tp2$ of the tubes 131 of a downstream row. Here, the pitches $Tp1$, $Tp2$ are distances between the centerlines CL of the tubes 131 in the

directions perpendicular to the air flow direction A1.

The tubes 131 in the same row are communicated with the same tank 133. In view of broad perspective, the refrigerant flows from the air upstream side to the air downstream side in the evaporator 13, as shown by arrows R1.

Next, an electronic control unit will be described. A control unit 22 includes a computer such as a microcomputer. The control unit 22 is programmed to control operation of the vapor compression refrigerant cycle system 5 based on signals from the following sensors and switches.

A temperature sensor 24 detects an inside temperature of the freezing container 2. The inside temperature is manually set with a temperature controller 25. For example, the inside temperature is set within a range between -10 degrees Celsius and -20 degrees Celsius.

A refrigerator switch 26 is manually operated. The refrigerant switch 26 produces on and off signals of the vapor compression refrigerant cycle system 5. An engine operation switch 27 produces signals in accordance with on and off states of the engine 8. A door switch 28 is located on a periphery of the opening 18. The door switch 28 is turned on and off in accordance with opening and closing of the doors 3, 4.

Further, the control unit 22 controls the electromagnetic clutch 7, the fans 10, 17, the defrosting valve 16, the blower unit 19 and the like.

Next, refrigerating operation of the vehicle 1 will be

described with reference to Fig. 8. During the vehicle running, the compressor 6 is driven by power from the engine 8 through the electromagnetic clutch 7. The fans 10, 17 are operated. Also, the vapor compression refrigerant cycle system 5 is on. With this, the air cooled by the evaporator 13 is blown into the freezing container 2 by the fan 17, thereby cooling the freights in the freezing container 2. At this time, the defrosting valve 16 is closed so that the refrigerant does not flow through the bypass 15.

When the engine 8 stops to carry in or out the freight, the fan 17 of a cooling unit 130 (Fig. 1) is turned off. Then, when the doors 3, 4 are opened, the door switch 28 is turned on so that the cross flow fans 20, 21 start operation. The air curtain is formed from the bottom to the top of the opening 18 to restrict entering of outside air.

At this time, the defrosting valve 16 is opened. By the pressure gap between the outlet of the compressor 6 and the upstream portion of the evaporator 13, the hot gas flows into the evaporator 13 through the bypass 15. Therefore, frost on the evaporator 13 melts into water and is discharged outside. When the doors 3, 4 are closed, the door switch 28 is turned off and the defrosting valve 16 is closed.

Next, advantages of the embodiment will be described.

Since the tubes 131 have the streamlined-shaped cross-sections, air smoothly flows along the outer surface of the tubes 131 without stagnating, as shown in Fig. 6C. It restricts moisture, which results in the formation of frost,

from condensing or adhering on the outer surfaces of the tubes 131. Thus, the growth of frost on the tubes 131 and further adhesion of frost particles thereon are limited. In the evaporator 13 of the embodiment, an amount of frost is reduced at substantially one fifth as compared with a prior evaporator.

Further, the formation of frost is restricted to the downstream portion of the tubes 131, as shown in Fig. 6C. Because the moisture does not adhere on the side surfaces of the tubes 131, it is less likely that the air passages between the tubes 131 will be obstructed by frost. Therefore, the resistance of air flow is not increased by the frost. Accordingly, cooling capacity of the evaporator 13 improves.

Because the tubes 131 are staggered, the tubes 131 of the downstream row are not located in thermal boundary layers generated by the tubes 131 of the air upstream row. Therefore, an efficiency of heat exchange of the evaporator 13 improves.

In the second embodiment, a cross-section of the refrigerant flow area of the most-downstream refrigerant passage 132 is larger than that of the most-upstream refrigerant passage 132, as shown in Fig. 9A.

Because the tubes 131 have the streamlined-shaped cross-sections, the adhesion of moisture on the tubes 131 is reduced. However, it is difficult to completely prevent the formation of frost. Although it is a small amount, the frost is formed at the downstream portions of the tubes 131.

Since the most-downstream refrigerant passage 132 has the flow area larger than that of the upstream refrigerant passage

132, a flow rate of the hot gas increases at the downstream portion of the tubes 131. Therefore, even if the downstream portion of the tube 131 is frosted, it is readily defrosted during the defrosting mode. The refrigerant passages 132 can have substantially rectangular-shaped cross-sections as shown in Fig. 9B.

In the third embodiment, the cross-sections of the refrigerant flow areas are changed in accordance with an outer dimension (thickness W) of the tube 131, as shown in Fig. 10. Also in this embodiment, the evaporator 13 provides advantages similar to the first embodiment.

In the fourth embodiment, the tubes 131 have streamlined-shaped cross-sections that are asymmetric with respect to the centerline CL, as shown in Fig. 11. Also in this embodiment, the evaporator 13 provides advantages similar to the first embodiment.

In the fifth embodiment, the tubes 131 are coated with a defrosting agent for restricting the moisture and frost particles from adhering on the outer surfaces of the tubes 131. For example, the defrosting agent includes a super-repellency coating and a material having water repellency, such as Teflon.

With reference to Fig. 12, for example, the temperature of the freezing container 20 is -20 degrees Celsius (T_1). When the doors 3, 4 open, outside air (e.g. 35 degrees Celsius, 60% relative humidity) enters the freezing container 2. The air is quickly cooled lower than the freezing point, and the inside air is supersaturated. Under the temperature T_2 , which is

lower than the freezing point, a small amount of vapor (M1) can exist as moisture (water vapor) in the inside air, for example.

Therefore, moisture (M2) contained in the outside air is supersaturated steam and is sublimated into sublimated particles without liquefying. The sublimated particles adhere to the outer surfaces of the tubes 131 and grow into frost. In the embodiment, the tubes 131 are coated with the defrosting agent. Therefore, it is less likely that the sublimated particles (frost particles) will adhere on the tubes 131. Accordingly, the growth of frost on the tubes 131 is restricted.

In the sixth embodiment, the evaporator 13 includes flat tubes 231 and tanks 233 as shown in Fig. 13. The tanks 233 are connected at the ends of the tubes 231. The tubes 231 are formed with a plurality of refrigerant passages 232 and produced by extrusion and drawing, similar to the first embodiment.

The tubes 231 are disposed such that the centerlines CL of the cross-sections are parallel to the air flow direction A1. Further, the tubes 231 are corrugated in directions perpendicular to the air flow direction A1, as shown in Figs. 13 and 14.

Straight portions 231b of the tubes 231 are connected through turn portions 231a. The tubes 231 are arranged such that the straight portions 231b are staggered, as shown in Fig. 14. An array pitch Tp 4 of the straight portions 231b of the

downstream tube 231 is smaller than an array pitch Tp_3 of the straight portions 231b of the air upstream tube 231, for example. Alternatively, the pitch Tp_3 and Tp_4 can be equal.

Also in the embodiment, the tubes 231 have streamlined cross-sections similar to the first to the fourth embodiment. Accordingly, the tubes 231 provide advantages similar to those of the first to the fourth embodiments.

In the seventh embodiment, the tube 231 has substantially an elliptic-shaped cross-section. The straight portions 231b of the tubes 231 includes substantially flat surfaces lying in parallel to the air flow direction A_1 , as shown in Figs. 15A and 15B. The upstream sides and the downstream sides of the straight portions 231b, which connect the flat surfaces, are gently curved.

As shown in Fig. 15C, air stagnating area is formed at the air downstream portion of the tube 231. The air stream around the tube 231 separates from the tube 231 and whirls at the downstream portion of the tube 231, as shown by arrows A_2 .

If moist air passes around the tube 231, moisture adheres on the downstream portion of the tube 231 and grows into frost thereon. Because the tube 231 is not provided with the outer fins, the frost only grows at the downstream portion of the tube 231 in the direction parallel to the air flow direction A_1 . It is less likely that the frost generates on the straight portions 231b to block the air passages therebetween. Therefore, the resistance of air flow reduces, hence the cooling capacity of the evaporator 13 improves.

As a modification, the refrigerant passages 132, 232 can have any cross-sectional shapes other than circular shape and square shapes. The array pitches Tp1, Tp2, Tp3, Tp 4 of the tubes 131 and the straight portions 231b can be changed. Also, the number of rows of the tubes 131 is not limited.

The present invention can be employed to a refrigerator for other purposes. For example, the present invention can be used for a cold storage. Further, the present invention can be employed to a heat exchanger that cools air with sensible heat. Also, the tubes having the streamlined-shaped cross-sections can be used for another heat exchanger that performs heat exchange between fluid and air, other than the heat exchanger for cooling air.

The present invention should not be limited to the disclosed embodiments, but may be implemented in other ways without departing from the spirit of the invention.